Title:

A Discussion of Two Challenges of Non-cooperative Satellite Refueling

Abstract:

There is interest from government and commercial aerospace communities in advancing propellant transfer technology for in-orbit refueling of satellites. This paper introduces two challenges to a Propellant Transfer System (PTS) under development for demonstration of non-cooperative satellite refueling. The PTS is being developed to transfer storable propellant (heritage hypergolic fuels and oxidizers as well as xenon) safely and reliably from one servicer satellite to a non-cooperative typical existing client satellite. NASA is in the project evaluation / planning stages for conducting a first time on-orbit demonstration to an existing government asset. The system manages pressure, flow rate / totalization, temperature and other parameters to control the condition of the propellant being transferred to the client. It keeps the propellant isolated while performing leak checks of itself and the client interface before transferring propellant. A major challenge is to design a safe, reliable system with some new technologies while maintaining a reasonable cost.

With specific enhancements / modifications also under development, the baseline PTS is readily applicable to other storable propellants (such as hypergolic oxidizer, monomethylhydrazine/MMH and xenon). These enhancements allow for servicing at different orbits including low earth orbit (LEO), geosynchronous orbit (GEO), or deep space fueling locations.

Of the various technology challenges of on-orbit refueling, the team has made significant advancements in modeling trapped volume vents and accurate flow metering.

As currently envisioned, there will be a planned operational release of GHe pressurant as well as small (several cubic centimeters) trapped volumes of propellant during refueling. This paper and presentation will cover specific modeling techniques (based on common available flow programs) being utilized by NASA to model vent dispersions to ensure proper design for protection of client satellite and satellite servicer assets.

In addition, any multiple client refueling operations will require a highly accurate flow metering / totalization method. This will be used to maximize the knowledge of the transferred propellant to the client and minimize the amount of propellant required to be stored in the servicing vehicle for cost effectiveness to shared multiple clients. This paper and presentation will cover specific flow metering / totalization technology concepts being evaluated and tested with simulant fluids and actual propellant commodities. Test results will be presented.

Presenter Bio:

Greg Coll - Propulsion Manager for the Satellite Servicing Capabilities Office SSCO at NASA GSFC. Manage propulsion systems effort for SSCO projects including technology development and future concept propulsion systems work.

Brian Nufer – SSCO lead fluids engineer at NASA KSC. Requirement, servicing con ops, design, and testing for technology development of the PTS.

Max Kandula - Ph.D. in mechanical engineering from the University of Illinois, Chicago. Principal thermal analyst including complex multiphase CFD of non-propulsive vents. He has published 41 journal articles, and presented 30 national and international conference papers in the areas of heat transfer, multiphase flow, CFD, high speed aerodynamics, and jet acoustics.

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Topic1 - Vent Research, Analysis and Characterization of Flashing Liquid Jets with an Extended Bubble Growth Model

The present refueling architecture includes a vent to space to expel the helium used during leak checks and evacuate the lines prior to filling the system with liquid up to the closed client servicing valve.

During the venting to space of hypergolic propellants, the superheated liquid jets flash, and droplets are dispersed towards the nozzle exit and can plug the flow under certain circumstances, which can be catastrophic to the mission. Currently data on flashing jets are available only for water, and none for hypergols, while no satisfactory theory exists to model flashing jets. The development of the present model helps to greatly reduce risk to the project by identifying relevant design parameters and optimize the vent configuration.

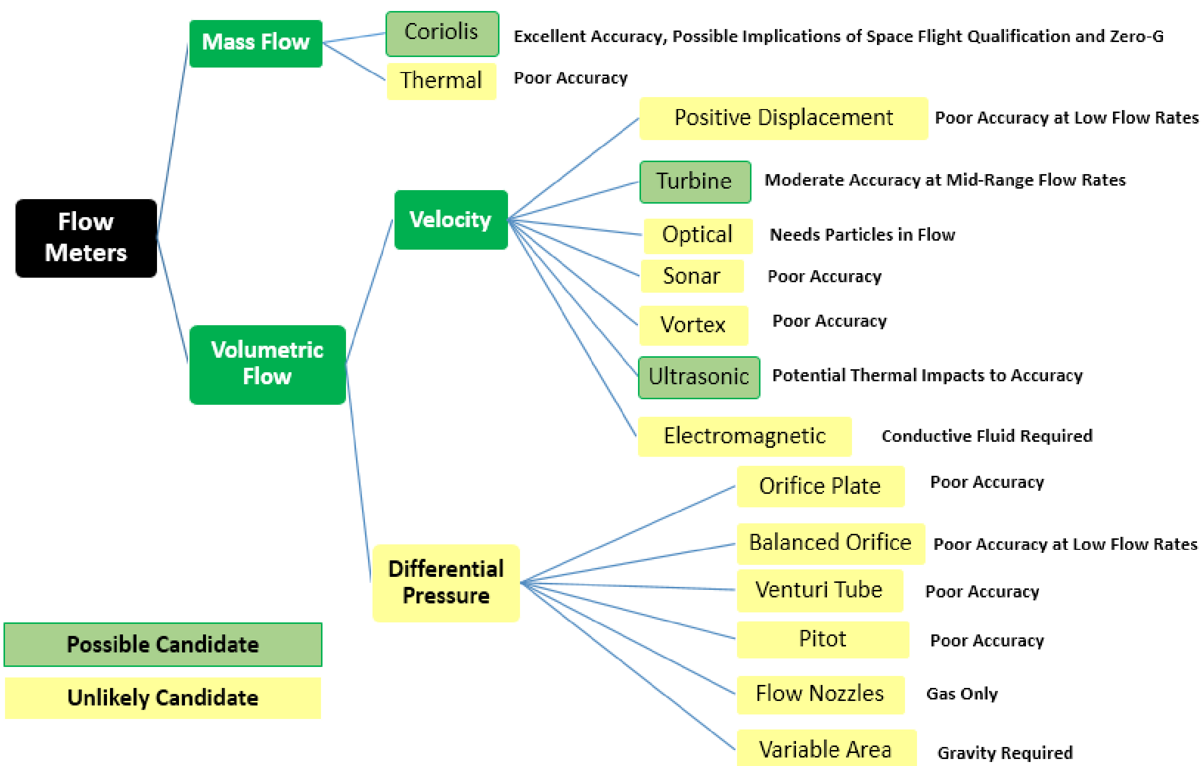
A theoretical model has been developed for the characterization of flashing superheated liquid jets vented into low pressure environment. The proposed work forms an extension of the well-known Mikic, Rohsenow and Griffith model (1970) for spherical bubble growth, accounting for the initial delay period associated with surface tension effect, which can become important for flashing jets. A criterion has been formulated for the disintegration (bursting) of superheated liquid jets with regard to bubble size relative to the jet diameter. The proposed model has been validated with test data for isolated bubble growth in an unbounded uniformly superheated liquid for a range of system pressures and liquid superheats. When applied to cylindrical liquid jets, the model compares favorably with existing test data for bursting lengths and included angles of water jets covering a wide range of jet initial temperature and velocity. It is concluded that liquid jets tend to burst when the bubble grows to a size four times that of the liquid jet. The results suggest that the jet bursting length decreases with an increasing jet initial temperature, and increases with an increasing jet initial velocity. On the other hand, the jet burst angle increases with an increasing jet initial temperature, and decreases with an increasing jet initial velocity.

Topic 2- Evaluation and Test of Liquid Propellant Metering with Totalization Technologies

This section covers a comparison of flow meter technologies for the precise measurement of liquid transfer.

Several flow meter technologies have been studied and tested to determine which technology meets the requirements for spacecraft propellant transfer systems. The design space allows for several technology options that meet client and servicing operation needs. These technologies were evaluated with water, CFC-113 and nitrogen tetroxide. Relative findings between the technologies will be presented along with a summary of relevant historic findings from previous testing by R.S. Baird on a separate program.

Many different technologies are shown in the following decision tree. The specific technologies that were studied in detail and subsequently tested include coriolis, positive displacement, turbine, ultrasonic, and balanced orifice meters. Relative to each other, the flow meters mentioned can be separated into two categories: highly accurate and moderately accurate. Depending on mission requirements, the need for a highly accurate flow meter may not be necessary thus allowing the project to pursue using technologies that may already have had a similar meter qualified for a launch and space environment. Highly accurate flow meters have not been flown in space and would require a rigorous qualification program to prove their suitability for the launch and space environments along with the impacts of these environments to the meter accuracy.



The accuracy impact of phenomena specific to particular technologies like fluid dynamic effects and fluid temperature will be discussed.

The selected flow meter technology will need to be integrated with a software system that calculates the propellant transferred in near real-time. An architecture for this software has been created and proven during ground testing. General findings related to this mass totalization software will be presented.